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ABSTRACT

Two paper and pencil group tests were assessed for their ability to classify subjects as concrete or formal operational. The two group tests, Sheehan's (1970) version of Longeot's three subtests and set of three puzzles, were administered to 607 students from ninth- and tenth-grade science and mathematics classes. A subsample of 69 students was involved in clinical interviews on a battery of three Inhelder tasks. Statistical analysis of test results were used to assess the correlations among subtests and test batteries and to provide a measure of the validity of the group tests. It was concluded that the tests used did provide a measure of concrete versus formal operations, but that both tests appeared to inflate the number of formal subjects. (Author/GK)

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PIAGETIAN DIAGNOSTIC TESTING OF SENIOR HIGH SCHOOL MATHEMATICS AND SCIENCE STUDENTS

BY

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The purpose of this study was to assess the extent to which two paper and pencil group tests could be depended upon to classify subjects as concrete or formal operational. It was assumed that the operational definition of formal versus concrete operations is provided by the responses to the Inhelder tasks (1958). Therefore, the purpose stated above is restated as the following major research questions:

1. What will be the relationship between classifications on replicated Inhelder tasks and classifications on each of two group tests?

2. What will be the relationship between group tests and between subtests of the same or different batteries?

3. What is the relative difficulty of the Inhelder tasks and the paper and pencil tasks?

4. Does the degree of difficulty of subtests of the same battery vary greatly?

5. To what extent will age, grade in school or sex correlate with classification on subtests?

BACKGROUND

In the past few years, there has been increased interest in the classification of adolescents and even adults in terms of Piagetian stage (Neimark, 1975). Piaget, himself (1972), has suggested that formal operations may not be attained by the widely-cited ages of 15 or 16. Given the hypothetico-deductive nature of formal thought and the curricular demands of secondary school mathematics and science, the possibility that a significant number of secondary school students are not formal operational raises serious implications for both curriculum and instruction.

Studies such as that reported by Renner and Stafford (1972) provide further support for this possibility, but their use of a stratified random sample of high school students leads one to suspect that the high percentage (66%) of concrete operational tenth, eleventh and twelfth graders may have been due to the performance of the large group of students typically in the "non-academic" track. However, the results obtained by McKinnon and Renner (1971),

Juraschek (1974) and Pluta (1980) with college students substantiate the existence of a large percentage of concrete operational students across both age ranges and academic tracks.

The importance of diagnosing the level of intellectual development of students has been attested to by many researchers and practitioners and has led to the development of diverse Piagetian-like tasks suitable for group administration. Many of these tests have been criticized for either their theoretical mismatch to Piagetian theory and/or the failure to adequately validate the group task. Valid criticisms of group tests include (1) the loss of the opportunity to probe for reasoning strategies, (2) the reading problem inherent in many of the tests, and (3) the loss of feedback from manipulating the equipment as in the Inhelder tasks (1958). However, researchers continue to construct group tests due to the multiple difficulties inherent in administering individual Piagetian tasks to large numbers of students.

Diagnosis of Piagetian stage, whether for research purposes or for eventual use of practitioners, is definitely a many-faceted problem. In the present study, two group instruments, a version of the Longeot (1962, 1964) tests and a set of three tasks researched by Karplus, Lawson and

Renner (Karplus et al., 1977) were administered to 607 students from ninth and tenth grade mathematics and science classes. One-third of the classes was designated as non-academic track. A subsample of 69 students was then administered a battery of three Inhelder tasks (shadows, solutions and bending rods). Statistical analyses of test results were used to assess the correlations among subtests and test batteries and to provide a measure of the validity of the group tests.

Method

Subjects

Eight school districts participated in the study. Although school districts were not used as a unit for analysis, school types included inner-city, rural-suburban, urban-suburban and small city. In each of four school districts department chairpersons selected three mathematics classes-- one tenth grade and one ninth grade from the academic track and one ninth grade non-academic track class. In the remaining four schools, three science classes were selected at the same grades and academic levels. A total of 607 students were available for the study. Although the majority of the students were ninth and tenth graders, there were a few eleventh and twelfth graders enrolled in these sections.

Due to absenteeism on one or both days of the group testing, 512 students completed the paper/pencil testing.

Materials

Sheehan's (1970) version of the Longeot subtests was used with one change. Question one of the logic subtest was rewritten as a sample question to correspond to Longeot's scoring directions. The ratio puzzle by Karplus, the volume puzzle by Renner and the mealworm puzzle by Lawson were used in the form given by Karplus et al. (1977) with two exceptions. The title of the ratio puzzle was changed to "Mr. Short and Mr. Tall" and the title of the volume puzzle became "The Water Puzzle" in order to avoid extraneous clues. All six subtests were arranged in a test packet designed to be administered during mathematics or science class on two consecutive days.

The entire research team had been collaborating on the preparations for the Inhelder tasks since June 1979. Equipment designs and interviewer's scripts evolved over a five month period. Script design was subject to several characteristics: (1) faithful replication of Inhelder's (1958) treatment, (2) the need to ensure maximum standardization in interviews, and (3) the need to identify

specific prompts essential as probing questions. Training of interviewers proceeded in the following sequence: (1) dry-runs of equipment and script drafts, (2) mock interviews with members of the research team role-playing subjects from the Inhelder and Piaget text, (3) interviews with senior high school volunteers from schools not in the study (The first such interviews were video-taped by the University TV crew. Three subsequent sets of interviews were held at three different sites using students from other classes. One set was video-taped.), (4) play-back of video-tapes for interview and scoring critique, (5) final critique of scoring guidelines, final scripts and cue sheets by the entire team. On the average, each interviewer had at least 15 hours of training devoted exclusively to the Inhelder tasks.

Procedures

Group testing occurred in the fall of 1979 within a two-week period in all schools. Classroom teachers administered the tests which had been packaged so as to eliminate the need for intermediate oral directions. Written guidelines for department chairpersons and classroom teachers indicated the general purposes of the testing and included

a set of guidelines to be used in talking to the students before the testing period. In addition, each test packet included administration directions. For example, test packets included gold pages for Day One of the testing and white for Day Two. Teachers were to monitor progress to ensure that on Day One no student began reading or working on Day Two material. Packets were collected from the schools and reorganized (1) to eliminate the data page containing student information, and (2) to separate the packet into the Longeot subtests and the Karplus et al. tasks.

The research team, consisting of eight graduate students and three faculty members had already developed scoring guidelines based on a literature search, written correspondence with Karplus and Lawson, and an examination of student responses from an earlier field study. The basis for all scoring decisions was faithful replication of the scoring and classifying procedures employed by the original researchers. In scoring Longeot's subtests, for example, a student could be classified II, IIIA or IIIB (concrete, early formal, late formal) on the logic test; IIA, IIB or III on the proportions test; and II, IIIA and IIIB on the test of combinations. A student was classified formal, III, on the Longeot battery if he/she had been classified formal,

early or late, on two out of three subtests. Scoring decisions on the three puzzles did not depend solely upon the number of items correct but also on the justifications written by each student. Students were classified as either II or III on the ratio and mealworm puzzles but, based on research by Renner et al. (1978), were classified as either II or IIIA on the volume puzzle. It was arbitrarily decided to classify a student as formal on the Karplus, Lawson, Renner (KLR) battery on the same basis as on the Longeot battery-- formal on two out of three puzzles.

In an initial working session one-half of the research team scored Longeot subtests while the remaining one-half scored KLR puzzles in order to identify and respond to any remaining scoring issues. Scoring teams then completed scoring all papers and crosschecked results. One-sixth of all papers were re-scored by the project directors as an added check on accuracy and consistency. In six cases, scorers were unable to classify a student on one of the KLR puzzles. Since each such subject was classified on two out of three puzzles as concrete in both cases or formal in both cases, the N for the paper/pencil batteries remained 512, but dropped to between 506 and 512 for some of the results based on subtest data.

In the first run of the data, four cells were generated, where F represents formal; C, concrete; K, KLR tasks ; and L, Longeot.

	F_L	C_L
F_K	F_K F_L	F_K C_L
C_K	C_K F_L	C_K C_L

Each student's classification was represented by a six-digit code, giving the score on each of the six subtests. However, all IIA, IIB and II classifications were collapsed into a single II category; a similar collapsing of data occurred for the various formal classifications. By this compromise measure, the researchers avoided the lack of differentiability associated with use of only the total score from Longeot or KLR . The totals for each cell are shown next.

	F_L	C_L
F_K	155	18
C_K	177	156

N = 506

It was decided to seek permission to test 20 students in each cell (18 in F_K C_L) in order to obtain at least 15 students per cell. In order to maximize the concrete/formal

distinction, students who scored formal on all three subtests and/or concrete on all three were selected. It was possible to follow this guideline in the F_K F_L and C_K C_L cells. In the C_K F_L cell, 16 students met the criteria. The other four students selected had scored concrete on the volume and mealworm puzzles but were formal on all three of Longeot's tests. Only one student in the F_K C_L cell was formal on all three *KLR* tasks and concrete on all three Longeot tests. A total of 78 permissions (20 from each cell except F_K C_L) were sent to parents via school distribution patterns. Seventy-one parental permissions were returned, 69 students were actually interviewed. (Two were absent on the days scheduled for interviewing.) This subsample consisted of 29 males and 40 females. There were 20 ninth grade non-academic track students, 24 ninth grade academic track and 25 tenth grade academic track students. The researchers chose to report the data from <u>all</u> students interviewed.

Five members of the research team, two faculty members and three graduate students completed all Piagetian interviews in an eight-day period. Interviewers worked in teams of two in 45 of the 69 interviews (each interviewer worked on <u>at least</u> two different teams), collected data on scripts and reached consensus on the final classification. Each

interviewer audiotaped comments after the subject had left. Each student was interviewed on all three tasks during a single class period (42-48 minutes). Students were told that the team was investigating the diverse ways students attack problems of the types frequently included in mathematics and science lessons. Paper and pencil were provided and students were reminded of its presence and its potential use "to keep track of ideas."

Completed scripts and audiotapes were crosschecked by the project directors before coding.

Results

The percentages of students who were classified as concrete or formal on each of the three Longeot tests, each of the three *KLR* tasks, and the combined two out of three for Longeot or *KLR* are reported in Table 1.

Table 1 about here

As can be seen in Table 1, the subsections which made up the *KLR* and Longeot tests varied greatly in difficulty. On the easiest task, the combinations section of the Longeot,

more than 3/4 of those tested were classified as formal. On the hardest test, the mealworm problem on the Karplus, only about 1/8 of the subjects attained a formal rating. When the criterion of two formal scores out of three was employed, about twice as many subjects were classified as formal by the Longeot as by the KLR .

Next, students who took the three Inhelder tasks were classified as formal or concrete on each task.

Table 2 about here

As with the Longeot and KLR , subjects needed to be classified as formal on at least two of the three tasks to be classified as formal on the total battery. Overall, the Inhelder tasks proved to be far more difficult than the KLR or Longeot tasks. Further, the shadows task was the most difficult of the tasks, with less than 5 percent of the students attaining a formal classification.

Since the data from the paper/pencil tests (KLR and Longeot) were for 506 to 512 subjects and that from the clinical interviews (Inhelder) for 69 subjects, the next step in data analysis was to examine the performance on paper/pencil tests of those students who took all three

tests. These results are summarized in Table 3.

Table 3 about here

As noted in the methods section, the 69 students to be given Inhelder tasks were not selected randomly, and the selection procedure accounts for the major differences in the percentages of students found formal on some tasks from the entire sample of 506 and the subsample of 69. A higher percentage of the subsample scored formal on the mealworm and ratio problems and a lower percentage scored formal on the combination and volume tasks.

As noted, each of the three tests consisted of three subtests which were scored as concrete or formal. As the next step in analysis, tetrachoric correlations were developed between each of the nine tests.

Table 4 about here

Several aspects of the correlational analysis deserve comment. First, the fact that there was a great disparity in the difficulty level of subtests within a test battery and also between test batteries forced the correlations to be

lower than if the test measures had resulted in a greater dispersion of scores. This effect is particularly evident when one examines the correlations between the shadows task and all other variables. None of these correlations are significant at the .05 level.

Second, the relationships among each of the subtests of the Karplus based on the total sample are .34, .54, and .50, while the relationships among the Longeot subtests are .60, .63, and .65. The subparts of the Longeot are more closely interrelated than the subparts of the KLR. However, the highest correlations obtained among the six subparts of the Longeot and KLR (.78) was between the KLR ratio test and the Longeot proportion test. In general, the KLR ratio and volume tasks related as highly to all three Longeot tasks as they did to each other. The KLR mealworm task was not closely related to Longeot subscores.

The effects of the sampling procedure are clearly seen in the relationships of subtest scores for the group of 69 students. Within subtest correlations are higher and between subtest correlations are generally slightly lower than for the entire sample.

As would be expected, the correlation between age and

grade (.90) was high. However, grade is related much more closely to eight of the nine subtests than age. One possible explanation for this apparent anomaly may lie in both the sampling procedure and the defined dichotomy for age and grade. Age was dichotomized as less than 180 months and equal to or greater than 180 months. Grade was dichotomized into ninth grade and tenth grade. There were twice as many ninth graders as tenth in the original sample and all tenth grade classes were in an academic track. One would expect the tenth grade academic track students to perform at a higher level than a mixed ability group of ninth graders. However, there was a scattering of older students in the ninth grade non-academic classes and the sampling procedures apparently resulted in the presence of a relatively high number of these students in the subsample.

Finally, the correlations between sex and the KLR subtests and two of the Inhelder tasks are all significant while the correlations between sex and the Longeot tests are almost non-existent. All these significant correlations are in favor of the male sex.

In Table 5 are presented the tetrachoric correlations between the KLR , the Longeot and the Inhelder considered as composite tests. All correlations are positive and

significant.

Table 5 about here

As described in the methods section, the sample of students in this study may be divided into three groups. Ninth grade students were selected from academic and non-academic sections of mathematics and science. Tenth grade students in mathematics and science courses are almost always in an academic track so that no subdivision was necessary for this group. The expectation for each subtest is for a decrease in the number of students classified as concrete for ninth grade non-academic, ninth grade academic, and tenth grade. Figures 1, 2, and 3 have been prepared for KLR , Longeot, and Inhelder tasks.

Figures 1, 2, and 3 here

For KLR subtests the expected trend is clearly seen for the ratio and volume task. As noted, the mealworm task was very difficult. About the same percentage of students in each group were classified as formal on this task. On the Longeot tasks the expected trend is evident for all three

tasks. On Inhelder's solutions and bending rod tasks a slight trend is evident, but the shadows task produced very few formal scores in any group.

All three of the tests employed in this study consist of three subtests. Performance on each subtest can be classified as formal or concrete. Both KLR and Longeot indicate that a person judged formal on two out of three of the subtests is really formal. Inhelder and Piaget talk of decalage in noting that individuals may be classed as formal in some cognitive operations but not in others. For purposes of this study, students judged as formal by two out of three of the Inhelder tasks were also classed as formal. In Figure 4 are displayed the percentage of ninth grade non-academic, ninth grade academic, and tenth grade students classed as formal on at least two of the three subtasks.

Figure 4 about here

In general, the expected developmental trends are confirmed, as well as the ordering of difficulty of the three tests. Formal status is most difficult on the Inhelder tasks and easiest to attain on the Longeot.

A question of interest in the student's performance on the Inhelder tasks was whether the order in which the tasks were taken would affect results. In each of these tasks the student received some feedback from the interaction with material. Although the three tasks were judged to be quite different, the possibility of learning from earlier tasks could not be ignored. In Table 6 are presented the rather strange data on order effect.

Table 6 about here

The shadow task, the most difficult of the three, was never scored at the formal level when the task was given first, but it was seldom scored formal when it was administered second or third. The solutions and rods tasks were scored formal more often when in the first or third position.

Discussion

The finding that the KLR was generally more difficult than the Longeot is surprising in view of the heavy reading load imposed by the Longeot and the appeal to the concrete (cartoon characters and pictures) of the KLR. However, two major considerations help to explain this finding.

First, the Longeot is almost entirely a multiple-choice test. No justification for choices is given. In contrast, written justification is essential in the *KLR* tasks. Second, on the one subtest of Longeot which is not multiple-choice, the student writes a set of permutations or combinations. Over 77.5 percent of the total sample were classified as formal on this subtest. Yet, according to Inhelder and Piaget (1958), the fact that a subject can write down all possible combinations does not necessarily imply the ability to use the system. Since use of the combinatorial system to make inferences characterizes the formal stage, the test of combinations may lead to an over-estimation of the number of formal students. The increased difficulty of the Inhelder tasks over both the Longeot and the *KLR* was expected despite the frequent assertion that verbalization of manipulative tasks increases the difficulty level for the student. The ability of the interviewer to probe for reasons and to clarify an initially misunderstood reason virtually eliminated the possibility that the subject might be classified incorrectly as formal when he/she was simply using intuition, inductive reasoning or an inconsistent reasoning pattern. Scorers of the *KLR* tasks had identified subjects with serious problems in reading

comprehension and written communication. However, the interviewers in the Inhelder tasks found that the use of manipulatives and the oral communication of the interviews did not substantially alter the classification attained by such subjects on the KLR . It may be more accurate to conclude that it is more difficult for a subject of the late-concrete stage (IIB) to be incorrectly classified as formal on the Inhelder tasks than on the KLR and the Longeot.

The most important question being addressed in this study was the viability of two group-tests to diagnose Piagetian stage. The correlations between the Inhelder tasks and either the KLR (.61, $p < .01$) or the Longeot (.55, $p < .05$) are positive, significant and they are moderately high. Although it is possible that the percentage of formal students on the Inhelder tasks would be even lower if a random sample had been used, there seems to be no question that KLR and Longeot do provide a measure of concrete versus formal operations. Since Longeot, and KLR to a lesser degree, appears to inflate the number of formal subjects, it would be better to assume that the majority of the subjects who are classified as formal on either of these batteries, fall somewhere along in the

range from late concrete (IIB) to early formal (IIIA).

To what extent, then, are the Longeot and the KLR potential diagnostic tools? Both tests are easy to administer with a minimum of guidance. However, the scoring of the KLR puzzles is far more complex than that of the Longeot. Therefore, the use of the KLR outside the realm of research has limitations.

Other findings reported in this paper include the relative difficulty of individual tasks or subtests. The shadows task was by far the most difficult of all the tasks. Almost all subjects eventually classified as IIB on this task verbalized the ratio concept and were aware of the correct ordering relationship (i.e., closer to the light, larger shadow). However, they were unable to conceptualize the equality between the ratio of ring sizes and the ratio of distances. The proportionality schema, as defined by the shadows task, may be a late acquisition of the formal stage.

Finally, the fairly high and significant correlation of sex with KLR and two of the Inhelder tasks and very low correlations with Longeot, in favor of the male sex is in agreement with other research on the higher achievement of males on tasks related to, or using, manipulative equipment.

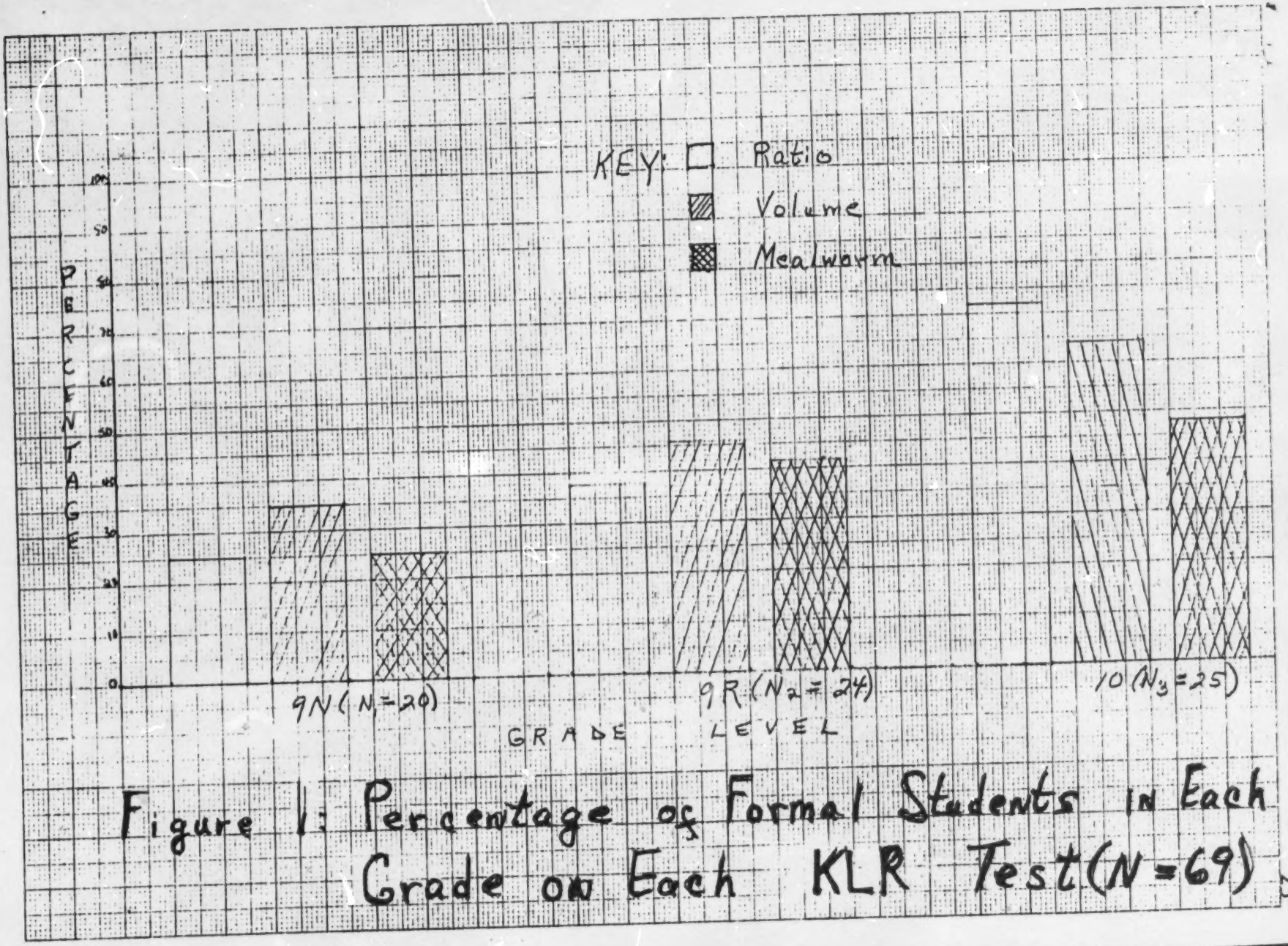

Figure 1: Percentage of Formal Students in Each Grade on Each KLR Test (N=69)

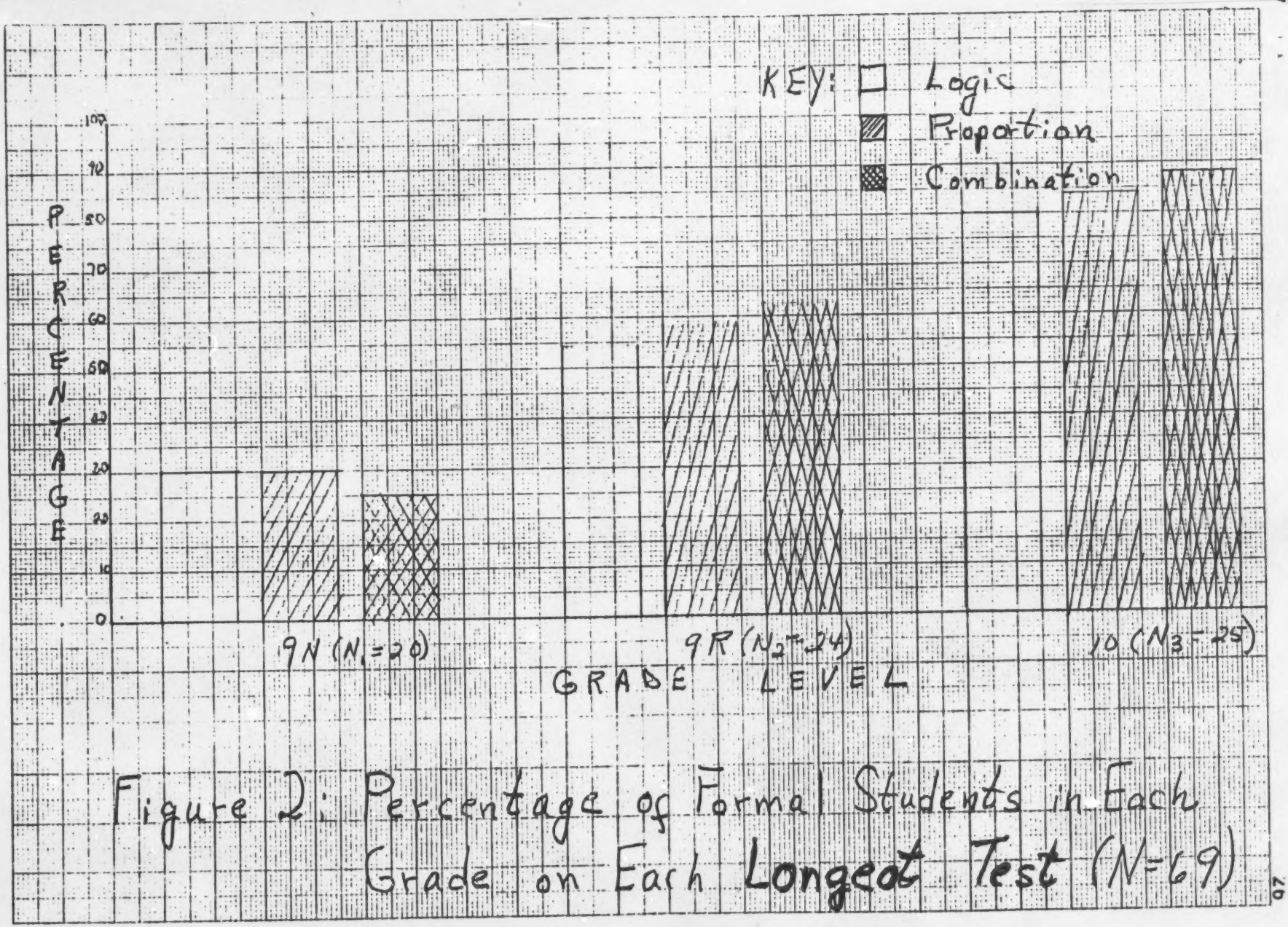

Figure 2: Percentage of Formal Students in Each Grade on Each Longeot Test (N=69)

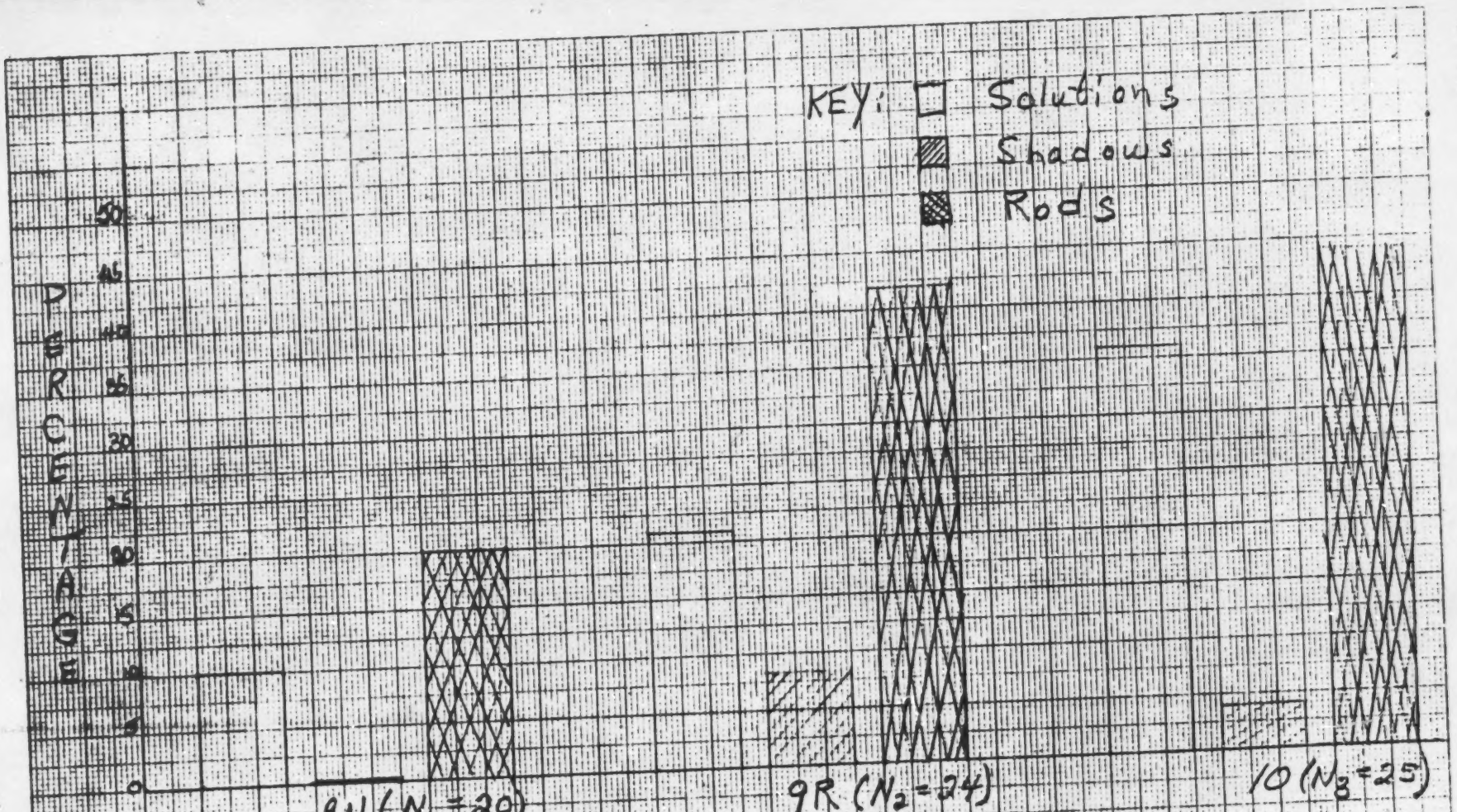

Figure 3: Percentage of Formal Students in Each Grade on Each Inhelder Task (N=69)

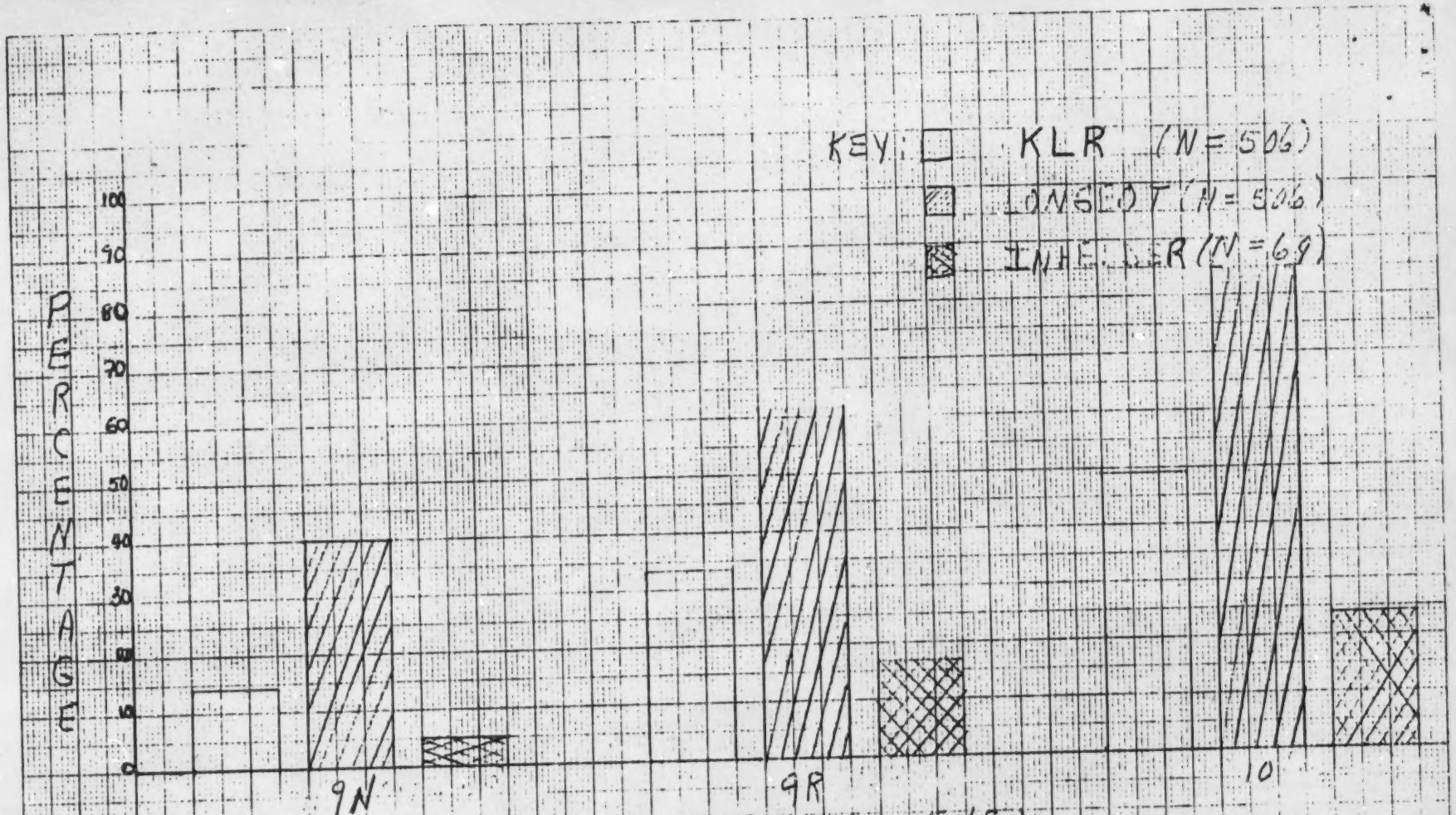

Figure 4: Percentage of Formal Students in Each Grade on KLR, Longeot and Inhelder

Table 6

Percentage of Students Classified as Formal on Each Task Order and on Each Task Irrespective of Order

	Order							
	1		2		3		"Average"	
Task	% Formal	Total N	% Formal	Total N	% Formal	Total N	% Formal	Total N
Solutions	28.6	21	15.4	26	27.3	22	23.2	69
Shadow	0	27	8.3	24	5.6	18	4.4	69
Rods	38.1	21	16.7	19	44.8	29	36.2	69

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Table 1

Percentages of Students Classified as Concrete and Formal on KLR and Longeot Tests
(N = 506)

	KLR				Longeot			
Classification	Ratio	Volume	Mealworm	Total	Logic	Prop.	Comb.	Total
Concrete	64.7	38.7	87.2	65.9	42.6	44.9	22.5	34.4
Formal	35.3	61.3	12.8	34.2	57.4	55.1	77.5	65.8

Table 2

Percentages of Students Classified as Concrete and Formal on Selected Inhelder Tasks (N = 69)

Classification	Task			Total
	Solutions	Shadows	Bending Rods	
Concrete	76.8	95.7	63.8	84.1
Formal	23.2	4.3	36.2	15.9

Table 3

Percentages of Subsample Classified as Concrete and Formal on KLR and Longeot Tests (N = 69)

	KLR			Longeot		
	Ratio	Volume	Mealworm	Logic	Prop.	Comb.
Concrete	53.6	50.7	60.1	43.4	40.6	39.1
Formal	46.4	49.3	39.1	56.5	59.4	60.9

Table 4

Correlations between KLR, Longeot, and Inhelder Tasks and Other Variables

	Karplus			Longeot			Inhelder			Other		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1 Ratio		86^{c}	66^{c}	53^{b}	55^{b}	51^{b}	56^{b}	49	59^{b}	57^{b}	38^{a}	59^{c}
2 Volume	54^{c}		97^{c}	07	17	22	52^{b}	45	54^{b}	66^{b}	20	36^{c}
3 Mealworm	34^{c}	50^{c}		36	49	46	35	58	50^{b}	43^{a}	07	22
4 Logic	47^{c}	47^{c}	14		97^{c}	96^{c}	54^{b}	35	58^{b}	04	02	58^{c}
5 Proportion	78^{c}	55^{c}	39^{c}	63^{c}		91^{c}	34	30	63^{b}	08	08	63^{c}
6 Combination	50^{c}	41^{c}	11	60^{c}	65^{c}		47^{a}	28	50^{b}	04	03	70^{c}
7 Solutions								67	52^{a}	63^{b}	02	41
8 Shadows									61	54	43	06
9 Bending rods										52^{b}	07	20
10 Sex											16	05
11 Age												90^{c}
12 Grade												

Correlations above the diagonal are for the subsample of 69 students.
Correlations below the diagonal are for the total sample of 506 students.
a : $p < .05$
b : $p < .01$
c : $p < .001$

Table 5

Correlations between the KLR , Longeot and Inhelder Batteries

Test	1	2	3
1 KLR	1.00	.67[c]	.61[b]
2 Longeot		1.00	.55[a]
3 Inhelder			1.00

a : $p < .05$ (N = 69)
b : $p < .01$ (N = 69)
c : $p < .001$ (N = 508)